CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1. General

The Displacement Based Design (DBD) procedure is involving to develop a new design method for reinforcement concrete structure based on several tremendous research work done in past by researchers all over the world. The beam-column design, performance of structure under different earthquake and the results obtain from the nonlinear time history analysis are the key work have done in this research work. There are some major points of this study is listed below:

1. Design response spectrum calculation from Indonesian earthquake database
2. Determination of design base shear and later force distribution
3. Determination of beam and column section properties
4. Selection of material, section and element types for modeling in OpenSees
5. Validation of proposed method through nonlinear time history analysis

6.2. Summary

The Displacement Based Design (DBD) is a based on performance based plastic design method which uses a pre-selected hazard and performance level of structure with respect a target spectrum. The design base shear is calculated using work-energy balance equations and the main point of the energy-work concepts is the work need to push the structure up to a target drift is equal to the energy need of an equivalent elastic-plastic single-degree-of-freedom (EP-SDOF) system to achieve the same condition. Moreover, a modification factor C2 is used to modify the design base shear parameters to consider the effect of pinched hysteresis behavior. Furthermore, the higher mode and inelastic state of structure based lateral force distribution method is applied on structure to get better lateral force distribution. The nonlinear time history analysis is performed in OpenSees which has a wide variety of material, section and element types to model a structure. Using NGA-West2 ground motion searching tools, 10 ground motion selected with a magnitude range from 6.5 to 7.6. In this study, four RC SMF structure is designed and performed nonlinear time history analysis to validate the DBD method according to selected performance level and seismic provisions. The maximum interstory drift ratio, relative story shear distribution and SCWB ratio from nonlinear analysis is validated the DBD method for vertically irregular RC SMF.

6.3. Conclusions

The following conclusions is made from this research work:

1. The design procedure of DBD is easy to follow for the designer. However, designer should be careful regarding unit of the parameters as it’s completely hand calculation based procedure.

2. Since the DBD is considered the nonlinearity of structure, the performance of structure under earthquake is better than expected performance level. The dynamic analysis of four RC SMF strongly support this statement.
3. The lateral force distribution is perfectly matched with the results obtained from the dynamic analysis of 10 selected ground motions. Almost all shear distribution pattern obtained from nonlinear analysis are very well fitted with the proposed lateral force distribution method. Hence, the method is reliable to apply on RC SMF with and without irregularity.
4. The performance level of structure is very satisfactory under strong earthquake. The maximum interstory drift results showed that the maximum story drift is very less than the target drift, even sometime it's less than the yield drift.
5. To avoid the soft story mechanism or localized story failure, it is important to include the concept of strong-column weak-beam on design methodology. The nonlinear analysis from OpenSees showed that the ratio of SCWB in columns is more than 1.3 which is desirable to avoid story failure. Hence, this statement is also support the superiority of DBD method for designing RC SMF.

6.4. Suggestions

1. The structure designed using DBD method needs to perform more nonlinear time history analysis using different materials, section and elements type other than used in this research.

2. The DBD method should be applied on different type structure like RC SMF with shear wall, RC Intermediate Moment Frame, RC Ordinary Moment Frame etc.
3. The soil interaction effects, higher target spectrum, higher target drift etc. should be analyzed by DBD method.

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APPENDIX A

Design Calculation of 8 story RC SMF (Table no according to chapter 5)

Table 5.1. Design base shear calculation of 8 story RC SMF

S No	Design Parameters	Equation No	Values
01	No Story		8
02	Floor Height, h (m)		28.5
03	Period, T (sec)	3.8	1.40
04	C_2	Table 3.4	1.07
05	Target Drift θ_u		0.02
06	Yield Target Drift θ_y		0.005
07	Modified Target Drift θ^*_u	3.9	0.019
08	Modified Ductility μ^*	3.10	3.74
09	Ductility Reduction Factor R^*_μ	Table 3.1.	3.74
10	Energy Modification Factor γ^*	3.11	0.46
11	Dimensionless Parameter α	3.7 & Table 5.2	1.38
12	Spectral Acceleration S_a	Figure 3.3	0.504
13	Design Base Shear Coefficient V/W	3.6	0.0872

Table 5.2. Lateral force distribution of 8 story RC SMF

Floor	h_j (m)	w_j (KN)	w_jh_j (KN-m)	$\sum w_jh_j$ (KN-m)	β_i	$\beta_i - \beta_{i+1}$	$\sum(\beta_i - \beta_{i+1})h_j$
8	29.00	1240.96	35987.84	35987.84	1.00	1	29.0
7	25.50	1240.96	31644.48	67632.32	1.56	0.56	14.3
6	22.00	1240.96	27301.12	94933.44	1.98	0.42	9.3
5	18.50	1240.96	22957.76	117891.2	2.31	0.33	6.1
4	15.00	1240.96	18614.4	136505.6	2.56	0.25	3.8
3	11.50	1240.96	14271.04	150776.64	2.75	0.19	2.1
2	8.00	1240.96	9927.68	160704.32	2.88	0.13	1.0
1	4.50	1240.96	5584.32	166288.64	2.95	0.07	0.3

Table 5.3. Beam design of 8 story RC SMF

Floor	M+ (KN-m)	M- (KN-m)	ρ'	ρ
8	62.66	150.57	0.010	0.005
7	97.85	235.10	0.015	0.008
6	124.32	298.73	0.020	0.010
5	144.87	348.11	0.023	0.011
4	160.68	386.08	0.021	0.010
3	172.37	414.17	0.023	0.010
2	180.31	433.26	0.023	0.012
1	184.71	443.84	0.025	0.012

Table 5.4. Exterior column moment and axial load of 8 story RC SMF

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
8	264.31	67.48	188.16
7	377.13	69.80	393.03
6	462.04	71.54	610.46
5	527.94	72.90	837.65
4	578.62	73.94	1072.35
3	616.11	74.71	1312.59
2	641.57	75.23	1556.61
1	655.70	175.87	1802.71

Table 5.5. Interior column moment and axial load of 8 story RC SMF

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
8	394.25	138.70	316.82
7	544.56	145.53	633.65
6	657.69	150.67	950.47
5	745.49	154.66	1267.30
4	813.02	157.73	1584.12
3	862.97	160.00	1900.95
2	896.89	161.54	2217.77
1	915.71	479.39	2534.60

Table 5.6. Interior and exterior column of 8 story RC SMF

Interior Column		Exterior Column	
Size (mm)	Rebar	Size (mm)	Rebar
900 x 900	8 # 16mm	750 x 750	8 # 16mm
950 x 950	8 # 16mm	800 x 800	10 # 16mm
950 x 950	10 # 16mm	800 x 800	8 # 19mm
1000 x 1000	10 # 19mm	850 x 850	10 # 19mm
1000 x 1000	12 # 19mm	850 x 850	10 # 19mm
1000 x 1000	14 # 19mm	900 x 900	12 # 19mm
1050 x 1050	14 # 22mm	900 x 900	12 # 19mm
1050 x 1050	14 # 25mm	900 x 900	14 # 25mm

Design Calculation of 4 story RC SMF vertically irregular (Table no according to chapter 5)

Table 5.1. Design base shear calculation of 4 story RC SMF (vertically irregular)

S No	Design Parameters	Equation No	Values
01	No Story		4
02	Floor Height, h (m)		15
03	Period, T (sec)	3.8	0.75
04	C_2	Table 3.4	1.15
05	Target Drift θ_u		0.02
06	Yield Target Drift θ_y		0.005
07	Modified Target Drift θ^*_u	3.9	0.017
08	Modified Ductility μ^*	3.10	3.48
09	Ductility Reduction Factor R^*_μ	Table 3.1.	3.48
10	Energy Modification Factor γ^*	3.11	0.49
11	Dimensionless Parameter α	3.7 & Table 5.2	2.43
12	Spectral Acceleration S_a	Figure 3.3	0.727
13	Design Base Shear Coefficient V/W	3.6	0.11

Table 5.2. Lateral force distribution of 4 story RC SMF (vertically irregular)

Floor	h_j (m)	w_j (KN)	w_jh_j (KN-m)	$\sum w_jh_j$ (KN-m)	β_i	$\beta_i - \beta_{i+1}$	$\sum(\beta_i - \beta_{i+1})h_j$
4	15.00	721.28	10819.2	10819.2	1.00	1	15.00
3	11.50	721.28	8294.72	19113.92	1.49	0.49	5.69
2	8.00	721.28	5770.24	24884.16	1.80	0.31	2.45
1	4.50	1240.96	5584.32	30468.48	2.08	0.28	1.25

Table 5.3. Beam design of 4 story RC SMF (vertically irregular)

Floor	M+ (KN-m)	M- (KN-m)	ρ'	ρ
4	24.35	58.51	0.005	0.0033
3	36.40	87.46	0.007	0.0041
2	43.85	105.37	0.008	0.0049
1	50.59	121.57	0.010	0.0065

Table 5.4. Exterior column moment and axial load of 4 story RC SMF (vertically irregular)

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
4	142.53	99.24	172.69
3	181.16	116.45	351.10
2	205.07	127.10	533.04
1	226.69	136.73	718.19

Table 5.5. Interior column moment and axial load of 4 story RC SMF (vertically irregular)

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
4	232.73	194.16	322.26
3	284.20	226.55	644.52
2	316.05	246.59	966.77
1	344.85	264.71	1289.03

Table 5.6. Interior and exterior column of 4 story RC SMF (vertically irregular)

Interior Column		Exterior Column	
Size (mm)	Rebar	Size (mm)	Rebar
600 x 600	6 # 16mm	600 x 600	6 # 16mm
650 x 650	8 # 16mm	600 x 600	6 # 16mm
700 x 700	8 # 19mm	650 x 650	8 # 16mm
700 x 700	10 # 19mm	650 x 650	10 # 16mm

<u>Design Calculation of 4 story RC SMF (Table no according to chapter 5)</u>

Table 5.1. Design base shear calculation of 4 story RC SMF

S No	Design Parameters	Equation No	Values
01	No Story		4
02	Floor Height, h (m)		15
03	Period, T (sec)	3.8	0.75
04	C_2	Table 3.4	1.15
05	Target Drift θ_u		0.02
06	Yield Target Drift θ_y		0.005
07	Modified Target Drift θ^*_u	3.9	0.017
08	Modified Ductility μ^*	3.10	3.48
09	Ductility Reduction Factor R^*_μ	Table 3.1.	3.48
10	Energy Modification Factor γ^*	3.11	0.49
11	Dimensionless Parameter α	3.7 & Table 5.2	2.72
12	Spectral Acceleration S_a	Figure 3.3	0.727
13	Design Base Shear Coefficient V/W	3.6	0.093

Table 5.2. Lateral force distribution of 4 story RC SMF

Floor	h_j (m)	w_j (KN)	w_jh_j (KN-m)	$\sum w_jh_j$ (KN-m)	β_i	$\beta_i - \beta_{i+1}$	$\sum(\beta_i - \beta_{i+1})h_j$
4	15.00	1240.96	18614.4	18614.4	1.00	1.00	15.00
3	11.50	1240.96	14271.04	32885.44	1.49	0.49	5.64
2	8.00	1240.96	9927.68	42813.12	1.80	0.31	2.48
1	4.50	1240.96	5584.32	48397.44	1.96	0.16	0.72

Table 5.3. Beam design of 4 story RC SMF

Floor	M+ (KN-m)	M- (KN-m)	ρ'	ρ
4	34.02	81.74	0.005	0.0033
3	50.85	122.18	0.008	0.0049
2	61.27	147.21	0.008	0.0049
1	66.81	160.53	0.011	0.0065

Table 5.4. Exterior column moment and axial load of 4 story RC SMF

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
4	219.97	152.01	219.97
3	273.94	172.36	273.94
2	307.34	184.96	307.34
1	325.12	191.66	325.12

Table 5.5. Interior column moment and axial load of 4 story RC SMF

Floor	M_{top} (KN-m)	M_{bot} (KN-m)	Pu (KN)
4	366.77	311.67	554.44
3	438.68	356.32	1108.89
2	483.17	383.95	1663.33
1	506.85	398.65	2217.77

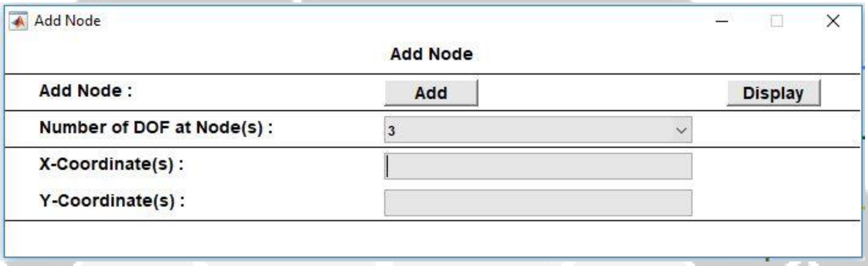
Table 5.6. Interior and exterior column of 4 story RC SMF

Interior Column		Exterior Column	
Size (mm)	Rebar	Size (mm)	Rebar
700 x 700	10 # 16mm	600 x 600	8 # 16mm
750 x 750	12 # 16mm	600 x 600	10 # 16mm
800 x 800	12 # 19mm	650 x 650	10 # 19mm
800 x 800	14 # 19mm	650 x 650	12 # 19mm

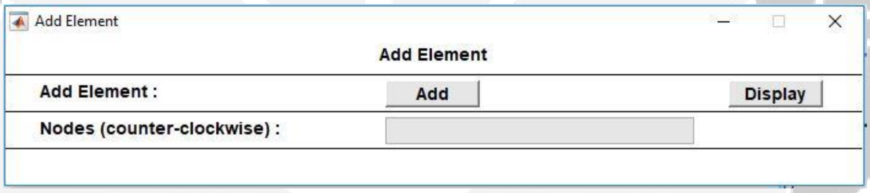
APPENDIX B

Nonlinear Modeling in OpenSeesNavigator

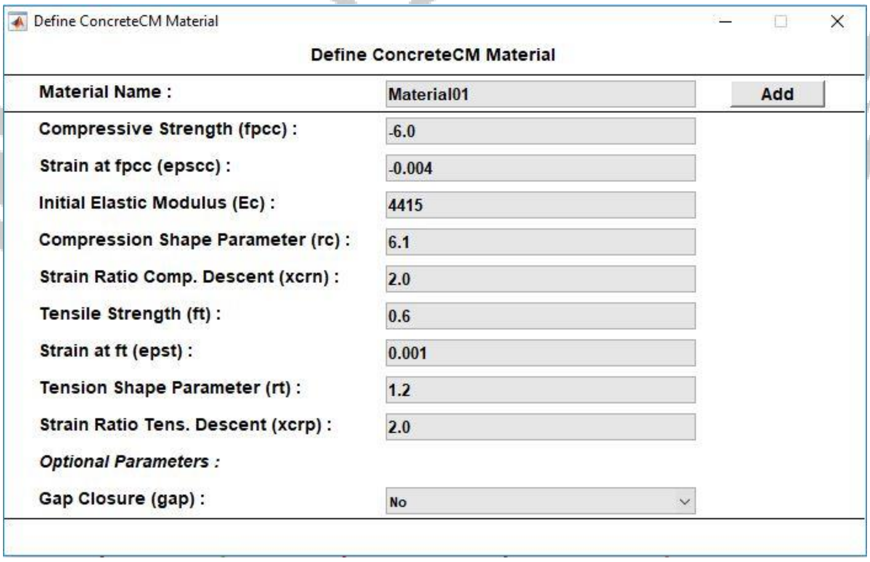
1. Add Node by putting X and Y coordinate values with DOF 3



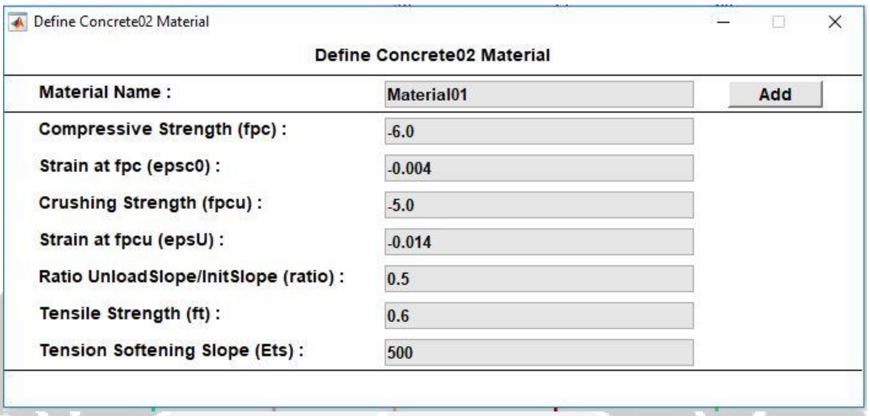
2. Add Element by using node number



3. Defining concrete material (unit in kips)

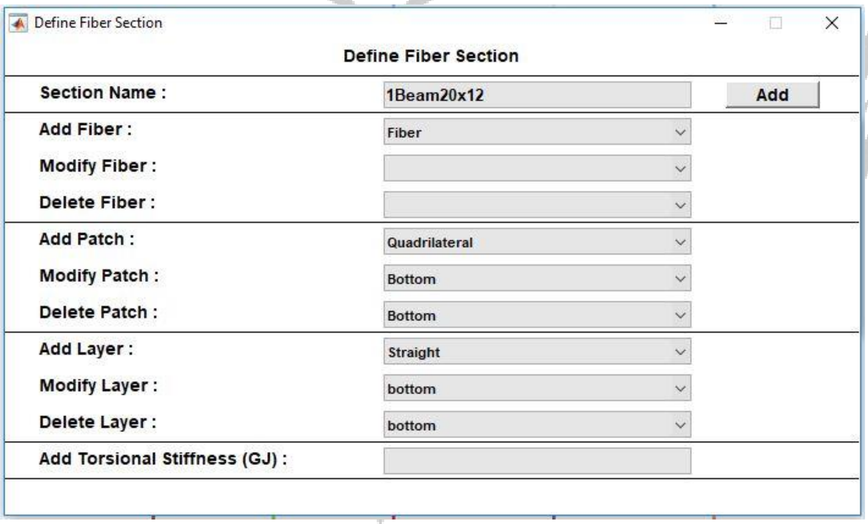


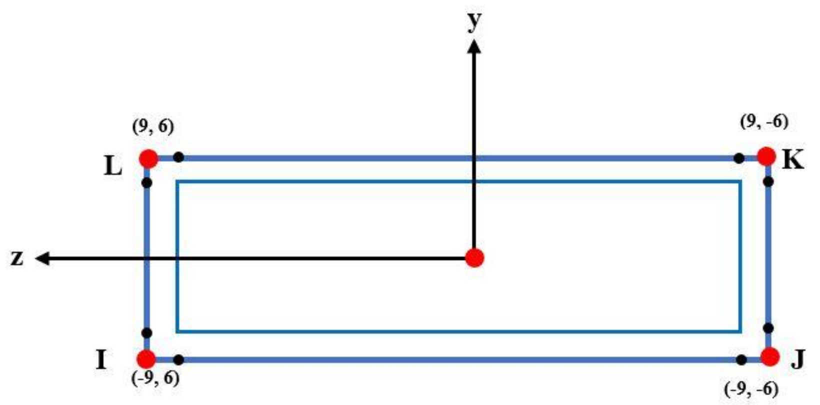
4. Defining steel properties (unit kips)

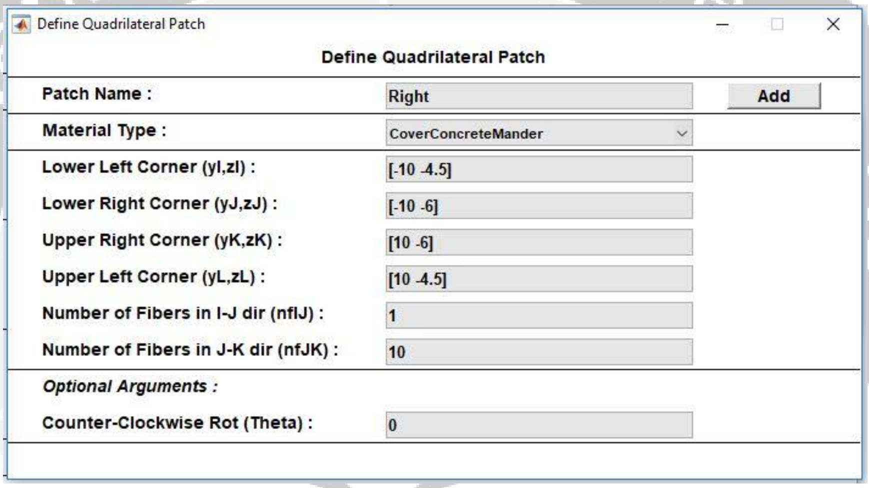


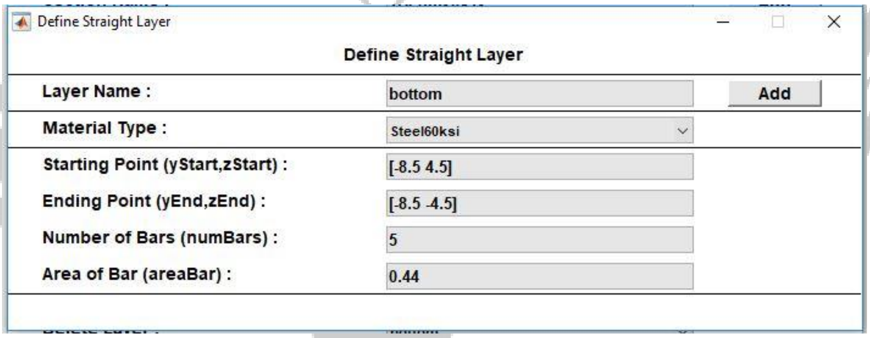
5. Defining fiber section

4 patches created for four side cover concrete and 1 patch created for core concrete. Straight layer is created for assigning rebar. An 18” X 12” beam section is presented in following figure. The section has two axis y & z with four corner point I J K L. The values of patches and layers are depends on the values according to y and z axis.

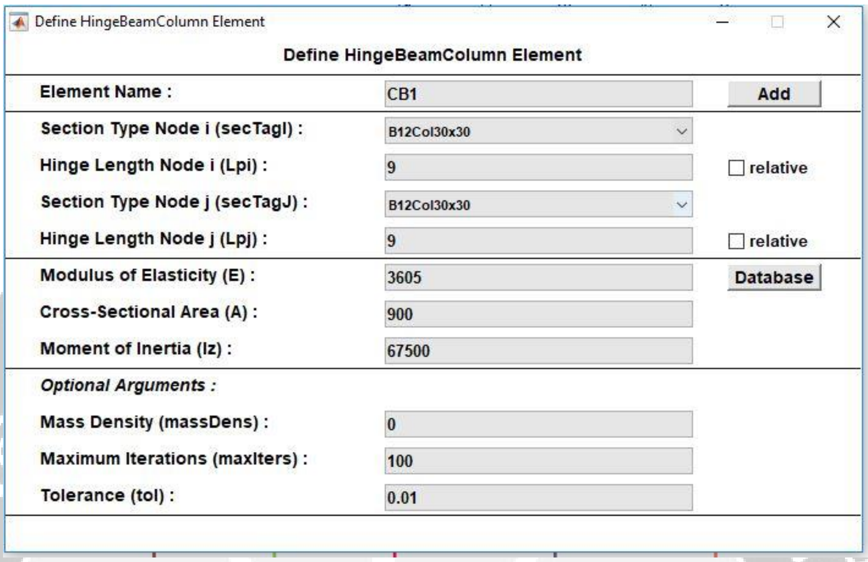



y
z
(9, 6)
L
(9, -6)
K
I
(-9, 6)
J
(-9, -6)

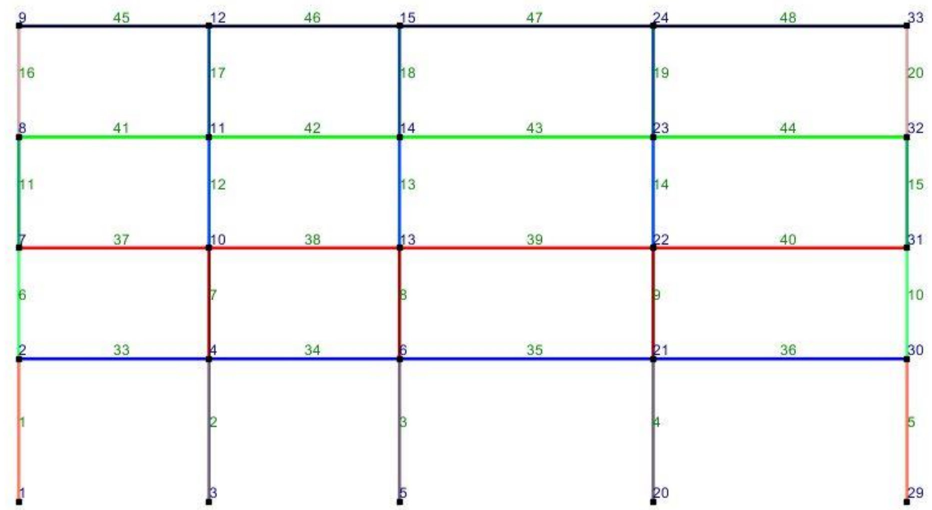

Define Quadrilateral Patch
Define Quadrilateral Patch
Patch Name :
Right
Add
Material Type :
CoverConcreteMander
Lower Left Corner (yI,zI) :
[-10 -4.5]
Lower Right Corner (yJ,zJ) :
[-10 -6]
Upper Right Corner (yK,zK) :
[10 -6]
Upper Left Corner (yL,zL) :
[10 -4.5]
Number of Fibers in I-J dir (nfIJ) :
1
Number of Fibers in J-K dir (nfJK) :
10
Optional Arguments :
Counter-Clockwise Rot (Theta) :
0


Define Straight Layer
Define Straight Layer
Layer Name :
bottom
Add
Material Type :
Steel60ksi
Starting Point (yStart,zStart) :
[-8.5 4.5]
Ending Point (yEnd,zEnd) :
[-8.5 -4.5]
Number of Bars (numBars) :
5
Area of Bar (areaBar) :
0.44

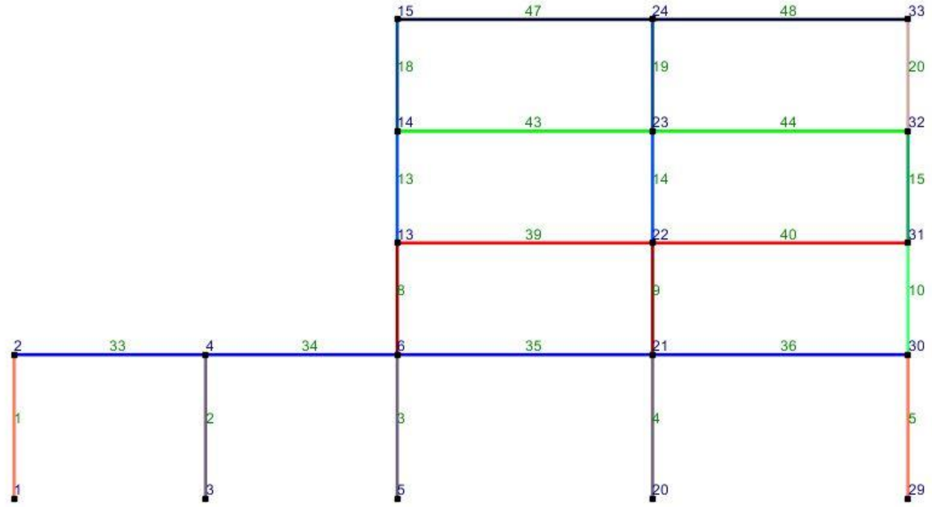
6. Define element (unit in kips-in)



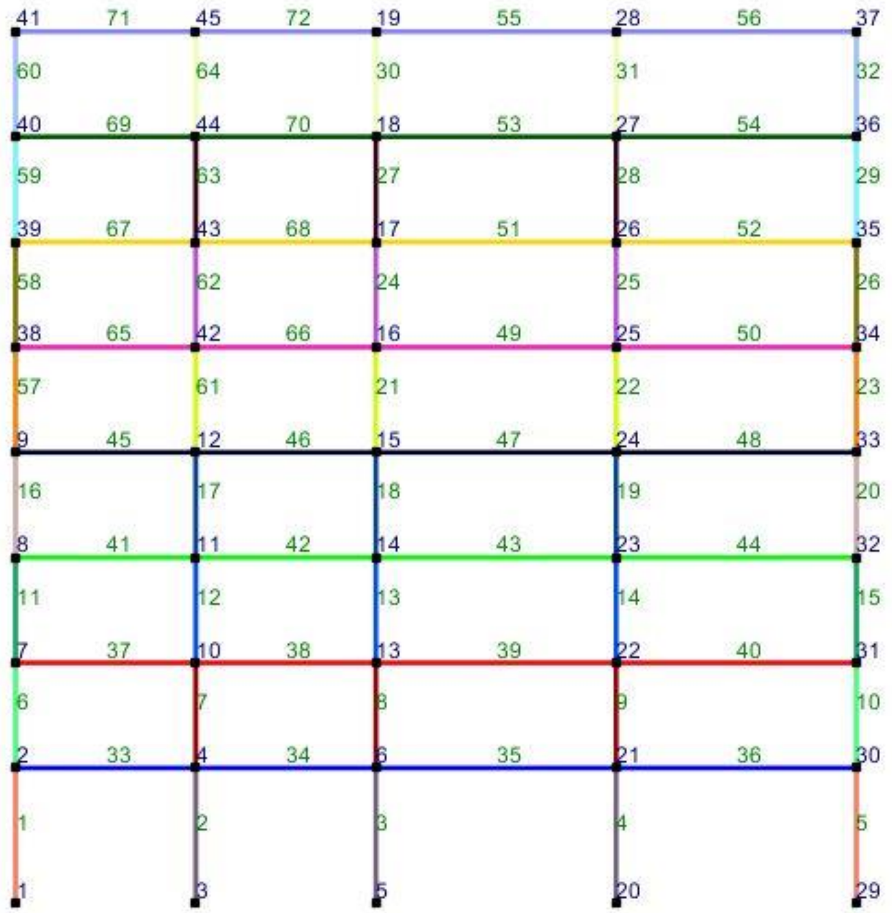
7. 4 Story RC SMF



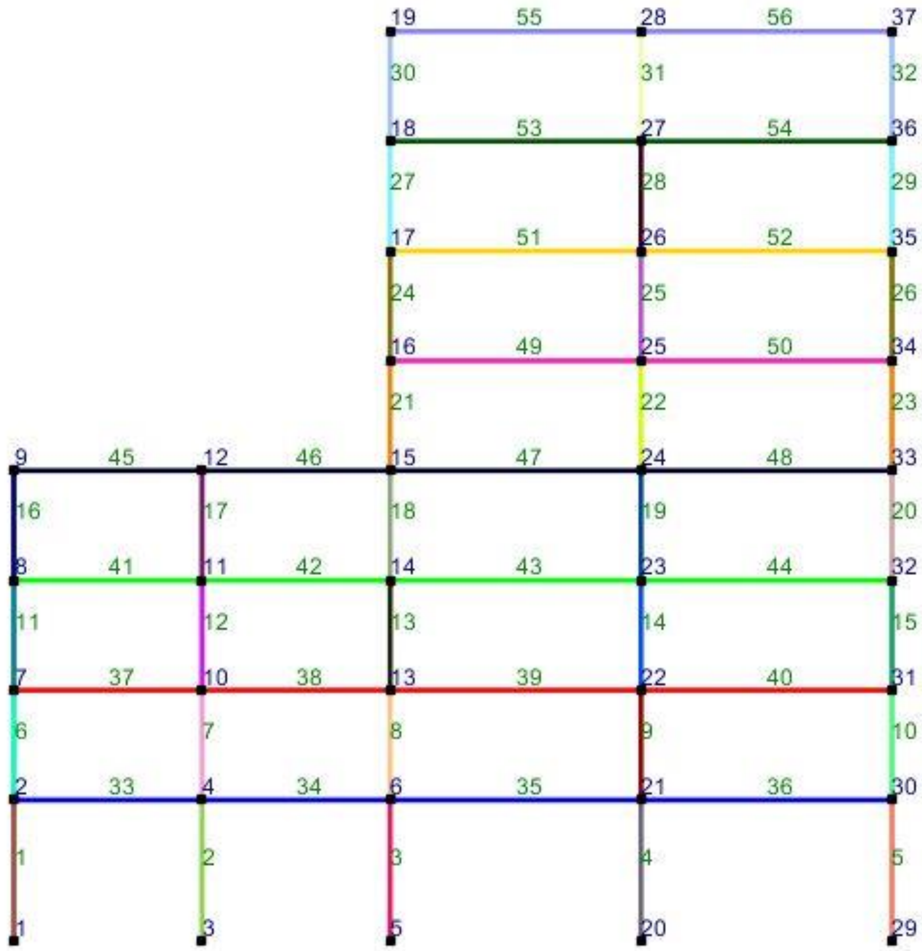
8. 4 Story RC SMF with vertical irregularity



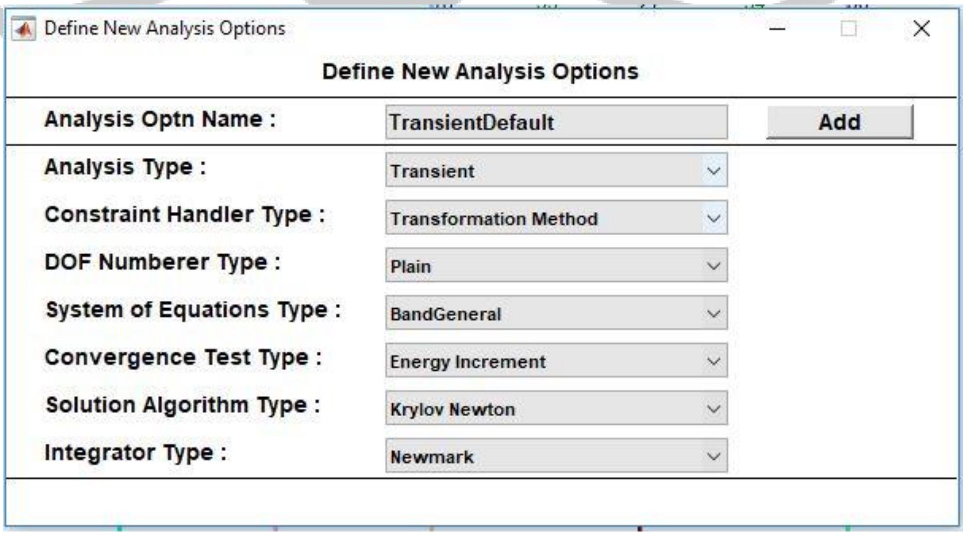
9. 8 story RC SMF



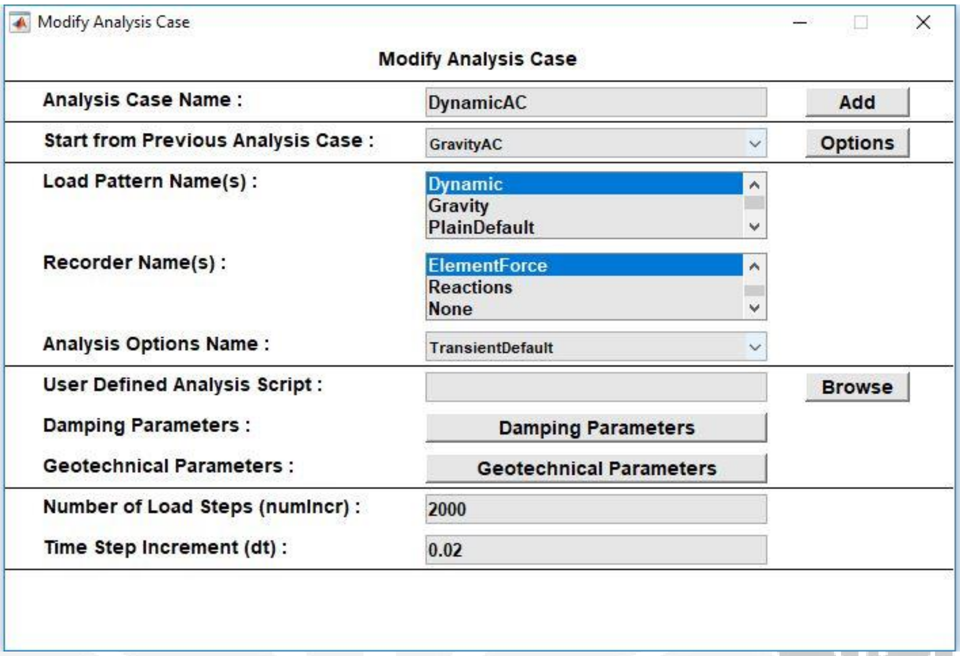
10. 8 story RC SMF with vertical irregularity



11. Analysis options

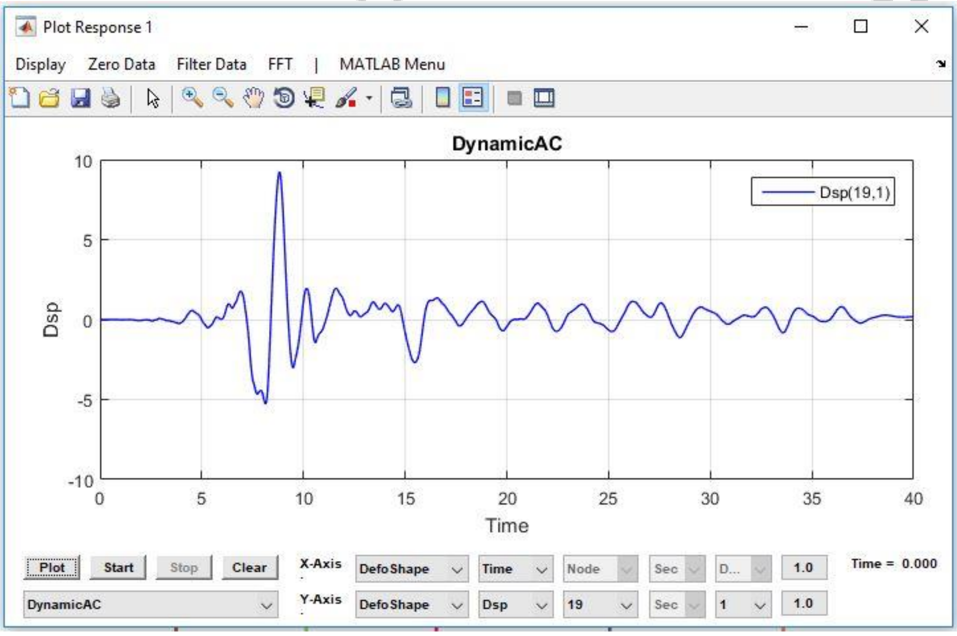


12. Analysis case



13. Results (deformation, unit in in)

19 no node is on top floor and DOF is 1 means X direction. Top floor displacement 9 in.



14. Results (Shear force of column, unit in kips)

Local force contain the axial, shear force and bending moment on DOF no 1, 2, & 3 respectively. The 19 no column shear force is 24 kips.